April 3, 1945. S. R. JORDAN 2,372,956

FEED-BACK CIRCUIT

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FIG. 1.

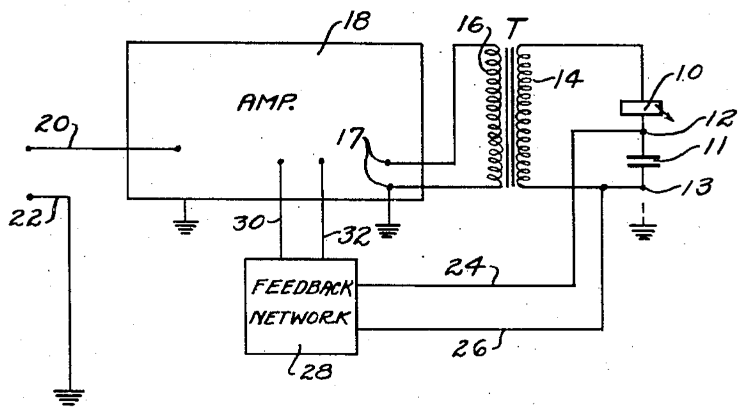


FIG. 3.

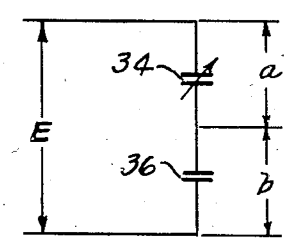
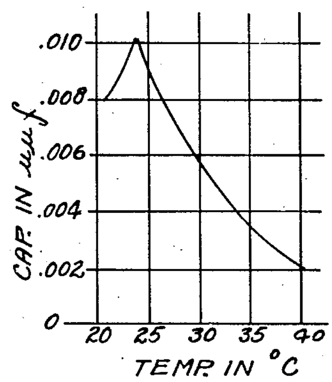


FIG. 2.



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FEED-BACK CIRCUIT

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4 Claims. (Cl. 179—100.4)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates to a temperature compensating circuit for use in connection with piezoelectric crystal motor devices such as recording cutting heads, earphones, loud speakers, oscilloscopes and other types of transducers which employ a piezoelectric crystal for converting electrical energy into mechanical energy.

One of the main difficulties encountered in the use of piezoelectric crystal motor devices arises from the fact that changes in temperature affect the amount which a crystal of this type will deflect for a predetermined applied voltage. That is, the sensitivity of the piezoelectric crystal is a function of temperature when the voltage is held constant. On the other hand, it has been found that the sensitivity is not a function of temperature when the charge is held constant. Inasmuch as piezoelectric crystal transducers are normally used in constant voltage systems rather than in constant charge systems, it follows that the amplitude of movement of the crystal element will vary with changes in temperature. This effect of temperature on the flexure of the crystal is due to the fact that the capacity of the crystal is a function of temperature. For example, a transducer crystal which has a capacity of 0.010 $\mu\mu$f. at 24° C. may have a capacity of only 0.002 $\mu\mu$f. at 40° C. Since the charge on a condenser varies directly with its capacity and with the voltage applied, it follows that a change in the capacity of the condenser will cause a corresponding change in the amount of charge thereon provided the voltage remains constant. This is expressed by the formula: $Q=CE$, where Q is the charge in coulombs, C is the capacity in farads, and E is the potential difference in volts. It thus becomes evident that in order to maintain the charge on a condenser constant when its capacity changes, it is necessary to so change the applied voltage as to compensate for the change in capacity.

In the past it has been customary to use a constant voltage system for driving the transducer crystal and to provide additional means for maintaining the temperature of the crystal constant so as to avoid the difficulty caused by changes in temperature. The provision of means for maintaining the crystal element at a constant temperature, however, complicates the construction of the crystal motor device and also renders it considerably more expensive to manufacture. In order to avoid the costly construction involved in this method of overcoming the difficulty, it has been recently proposed to reduce the temperature effect on the transducer crystal by placing a zero temperature coefficient condenser in series with it so as to maintain the charge on the crystal more nearly constant. This expedient is fully described in an article by A. J. Begun in the Society of Motion Picture Engineers Journal for June 1941 at page 666. In accordance with this article it is proposed to use a series condenser whose capacity is the same or slightly lower than that of the crystal. As pointed out in the article, however, such a system will not completely compensate the transducer crystal for changes in temperature and an additional temperature control means must be provided for overcoming the change in the sensitivity of the crystal with changes in temperature.

With a view to overcoming the above-mentioned difficulty in a simple and convenient manner, the present invention contemplates the use of a feed-back circuit to maintain the amplitude of flexure of the crystal relatively constant in spite of temperature fluctuations. Thus, the necessity for elaborate means for maintaining the temperature of the crystal constant by electrical heating devices, etc., is eliminated and a considerable saving in size, space and cost of the crystal motor may be effected.

Accordingly, one of the objects of the present invention is to provide a simple and inexpensive temperature compensating circuit for a piezoelectric crystal motor device.

Another object of the invention is to provide a novel type of feed-back circuit for overcoming the temperature effect on a piezoelectric crystal motor device.

Still a further object of the invention resides in the provision of a negative feed-back network for applying the voltage appearing across a condenser connected in series with the piezoelectric crystal motor to the amplifier used for driving the crystal motor.

A preferred embodiment of the present invention will be hereinafter described with reference to the accompanying drawing, given merely by way of example, in which

Figure 1 is a circuit diagram of an amplifier and a piezoelectric crystal transducer unit driven thereby wherein a negative feed-back network is utilized for overcoming the variations in flexure of the crystal with changes in temperature;

Figure 2 is a graph showing the variation in the capacity of a typical transducer crystal with changes in temperature; and

Figure 3 is a wiring diagram of the transducer crystal and series-connected condenser.

It will be seen from Figure 2 that the capacity of a typical piezoelectric crystal transducer unit is highest in the neighborhood of the Curie point (i. e., about 23.5° C.) and falls off rapidly on either side of this point when the temperature is increased or decreased. As a result of this characteristic of the crystal it will be evident that, since the flexure of the crystal depends upon the electrical charge impressed upon it, if the voltage applied to the crystal is maintained constant and the temperature of the crystal is varied from say 23½° C. to 40° C., the charge on the crystal will be considerably reduced because of the decrease in capacity. Consequently the flexure of the crystal will likewise be reduced, since it is a function of the charge thereon. The use of a substantially zero temperature coefficient condenser in series with the piezoelectric crystal motor as proposed by A. J. Begun in the above-mentioned article, will tend to correct this difficulty in a constant voltage system, but unless the impedance of the series condenser is made many times higher than that of the crystal so as to effectively "swamp out" the effect of temperature on the latter, the correction will not be sufficient for high fidelity reproduction. However, if the impedance of the condenser is made large enough to "swamp out" the effect of temperature on the crystal, then the voltage impressed across the crystal will be so small at ordinary operating voltages that the amplitude of flexure of the crystal will be too small to be useful. For example, if the input voltage to the series-connected crystal and condenser (represented as E in Figure 3) is taken to be one hundred volts R. M. S. and the impedance of the condenser 36 is thirty times that of the crystal 34, then the voltage *a* impressed across the crystal 34 will be in the neighborhood of three volts R. M. S., while the voltage *b* across the condenser 36 will be in the neighborhood of 97 volts R. M. S. Hence, serious difficulty will be encountered in providing a sufficiently high output voltage E for obtaining a useful voltage across the crystal which in many cases must be in the neighborhood of one hundred volts R. M. S.

In order to obviate this difficulty a novel application of negative feedback has been utilized in the present invention for maintaining the charge on the crystal substantially constant. As shown in Figure 1, piezoelectric crystal transducer unit 10 which may take the form of a cutting head, a loud speaker, an oscillograph recording instrument, etc., is connected in series with a condenser 11 across the output of the secondary winding 14 of a coupling transformer T. The condenser 11 is preferably chosen to have a capacity equal to or somewhat greater than that of the transducer unit 10 and should also have a substantially zero temperature coefficient. The primary winding 16 of the coupling transformer is connected to the output terminals 17 of a vacuum tube amplifier 18. The signal voltage for operating the transducer crystal is applied to the input terminals 20 and 22 of the amplifier 18. In accordance with the present invention a feedback voltage is taken off the condenser 11 at points 12 and 13, after which it is led through the conductors 24 and 26 to a negative feed-back network 28. From this network a negative or inverse feed-back voltage is derived and applied through the conductors 30 and 32 to one of the amplifier stages of the amplifier 18 so as to stabilize the output voltage across the condenser 11. It will be evident that if the voltage across the condenser 11 is maintained constant, the charge thereon must likewise remain constant; and, since the transducer crystal and the condenser are connected in series, the charge on the crystal will be equal to that on the condenser and hence also constant. This effect may be accomplished through the negative feed-back arrangement shown in Figure 1, since, if the voltage across the condenser should tend to increase due to the effect of temperature upon the transducer crystal, a slightly higher negative feed-back voltage will then be applied to the amplifier 18 so as to reduce its gain and thereby reduce the output voltage applied across the crystal and condenser. In a similar manner, if the voltage across the condenser 11 should tend to decrease, then a lower negative feed-back voltage will be applied to the amplifier and the gain will thereby be increased to apply a higher output voltage to the crystal 10 and condenser 11. In this manner the crystal 10 is caused to operate in what amounts to a constant-charge system, and consequently temperature changes will not affect the amplitude of flexure of the crystal.

Since, through the use of negative feedback, the impedance of the condenser 11 may be made equal to or even smaller than the impedance of the crystal 10, the voltage loss due to the use of the condenser will not be serious. Furthermore, since only a moderate amount of negative feedback need be used for the purpose of accomplishing the intended result, the gain of the amplifier 18 will not be seriously reduced thereby, and a conventional audio-frequency amplifier may be utilized for the purpose of carrying out the present invention.

If the negative feed-back voltage is returned to an element of the amplifier 18 which is maintained at ground potential (i. e., a control grid) then the point 13 of the crystal circuit may be connected to ground as indicated by the dotted line in Figure 1. However, if the feed-back circuit is connected to a screen grid or to a plate which is maintained at a potential above ground, then the point 13 should be connected to a positive B supply voltage of equal potential, thereby neutralizing the D. C. voltage applied to the lower side of the crystal through the feed-back connection. That is, the voltage applied at the point 13 is applied to the top of the crystal by reason of the transformer winding 14 and also to the bottom of the crystal by reason of the feedback network 28 and by maintaining both sides of the crystal at the same positive potential, there will be no biasing of the crystal and therefore no possibility of distortion being introduced in the final output. In some instances, however, it may be found desirable to provide a variable tap on the B+ supply for the crystal circuit return so as to enable a constant potential difference to be applied across the crystal and hence place a constant bias thereon of any desired amount.

While a novel application of the feed-back circuit has been described in connection with certain types of piezoelectrical crystal devices, it is not intended that the invention should be limited to use with these specific devices nor that it should take the exact form herein shown and described.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A piezoelectric crystal transducer system comprising an amplifier having an output circuit, a piezoelectric transducer unit and a condenser electrically connected in series across said output circuit, and means for inversely feeding back a portion of the voltage appearing across said condenser to said amplifier so as to maintain the voltage across said condenser substantially constant.

2. A piezoelectric crystal transducer system comprising an electronic amplifier having an output circuit, a piezoelectric crystal transducer unit and a substantially zero temperature coefficient condenser electrically connected in series across said output circuit, and a negative feed-back circuit for applying a portion of the voltage appearing across said condenser to said amplifier so as to maintain the charge upon said transducer unit substantially constant irrespective of changes in temperature of said unit.

3. The invention as defined in claim 2 wherein the capacity of said series condenser is substantially equal to that of said piezoelectric transducer unit.

4. The invention as defined in claim 2 wherein said output circuit includes an output transformer having a primary winding and a secondary winding, said transducer unit and said condenser being connected in series across said secondary winding.

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